MECHANICAL ENGINEERING UPGRADES TO THE DARHT-II INDUCTION CELLS*

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Abstract

Recent performance and reliability upgrades to the Dual Axis Radiographic Hydrodynamic Test (DARHT) facility second axis induction cells have impacted various cell mechanical components. To attain a higher level of performance and reliability, key mechanical elements comprising the induction cells were redesigned. These elements include the oil-vacuum insulator assembly, cathode cap, oil and vacuum region cell extension hardware, induction cores' insulating material and configuration, and the high voltage drive plate. While developing these upgrades, other enhancements, unrelated to the electrical performance, were implemented as well. These enhancements include the solenoid assembly oil-water interface, the oil plumbing and ventilation, and the vacuum bellows assembly. Mechanical processes were also developed to attain high assembly quality during the cell refurbishment process. This paper presents and discusses each mechanical attribute associated with these upgrades of the DARHT second axis induction cells.

I. INTRODUCTION

Figure 1 shows a cross sectional view of the new DARHT-II induction cell design. After extensive research and development, this design has demonstrated high performance and reliability during the testing of prototypes and during the rigorous implementation of the cell baseline acceptance program [1]. Among several improvements, four key upgrades associated with the pulse power functions affected the design of mechanical components. These include modifications to the insulator assembly, revising the new cathode field shaper (i.e. cathode cap) attachment method, mechanical extension hardware to increase the cell length by 1-inch, inter-core insulating configuration, and modifications to the high voltage drive plate. Additional upgrades that are not directly associated with electrical performance were introduced to improve reliability and maintainability during lifetime operations, which includes hermetically sealing the water-oil interface joint in the solenoid, improving the ventilation of the oil cavity to prevent overpressure, and incorporating a detachable bellows assembly. These upgrades will be implemented on eighty cells in a quality production process environment that promotes assembly repeatability which leads to reliable cell performance.

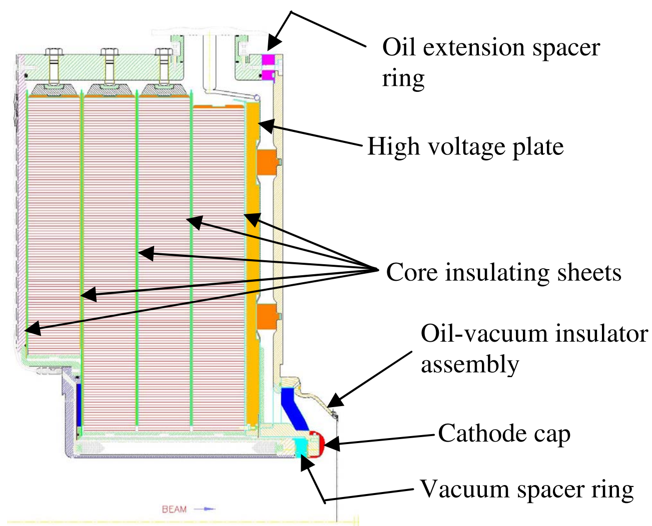

Figure 1. Cross sectional view of new DARHT-II induction cell indicating key mechanical upgrades.

II. PULSE POWER COMPONENTS

A. *Insulator Assembly*

Each cell's insulator assembly will have its cathode side triple point region modified to the "Flatface-2" geometry. As shown in Figure 2, this new geometry involves

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14. ABSTRACT
Recent performance and reliability upgrades to the Dual Axis Radiographic Hydrodynamic Test (DARHT) facility second axis induction cells have impacted various cell mechanical components. To attain a higher level of performance and reliability, key mechanical elements comprising the induction cells were redesigned. These elements include the oil-vacuum insulator assembly, cathode cap, oil and vacuum region cell extension hardware, induction cores insulating material and configuration, and the high voltage drive plate. While developing these upgrades, other enhancements, unrelated to the electrical performance, were implemented as well. These enhancements include the solenoid assembly oilwater interface, the oil plumbing and ventilation, and the vacuum bellows assembly. Mechanical processes were also developed to attain high assembly quality during the cell refurbishment process. This paper presents and discusses each mechanical attribute associated with these upgrades of the DARHT second axis induction cells.

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performing a precision radial cut that spans across three materials: Mycalex ceramic, a 0.010-inch thick epoxy glue joint, and a stainless steel cathode flange. The direction of this cut is tactically performed in a radially inward direction, sequentially cutting from the Mycalex to the epoxy glue joint and to the stainless steel. This method prevents stainless steel fragments from becoming imbedded in the epoxy joint, a condition that can be detrimental to the performance of the cathode triple point region. Machining Mycalex requires the use of carbide or diamond tip tooling and is cooled by applying liberal amounts of dionized water during cutting.

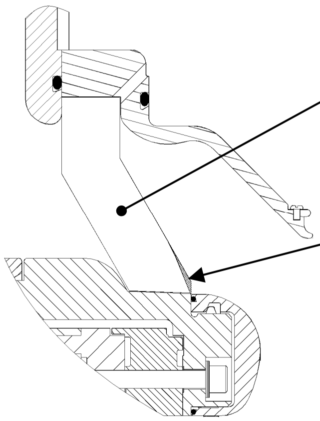

Figure 2. Oil-vacuum insulator assembly modification to Flatface-2 geometry

A second modification is the machining of radial tapped holes to accommodate locking set screws for securing a threadless mounted cathode cap, discussed in the following section. These holes are fitted with locking Helicoil inserts to prevent loosening of the locking set screws during operation.

A finite element stress analysis, summarized in Table 1, shows that the safety factors (SF) do not differ significantly between the legacy and the "Flatface-2" designs. This confirms the minimal impact to the mechanical strength of the modified design.

Table 1. Comparison of stress values for Legacy and Flatface-2 insulator assemblies

	Maximum glue line stress		**Maximum insulator (principle) stresses Tension/Compression**	
Geometry	**psi**	**Yield SF**	**(psi)**	**Failure SF**
Legacy	406	11.1	555/-771	10.8/ 63.3
Flatface-2	441	10.2	806/-750	7.4/ 60

B. Cathode Cap

Experience with the legacy cathode cap revealed two mechanical problems associated with its 13.5-inch diameter mounting thread. Figure 3 compares the legacy and new cathode cap design. The first problem found was due to a close tolerance fit between the thread engagement and the mating cylindrical surfaces. Although the threads were plated with silver for lubrication, the cathode cap would occasionally seize to its mounting flange because of galling between un-plated similar metals (stainless steel). Once galling occurs, the only means to remove the cap is by grinding or machining it off in situ. This process has the inherent risk of damaging the insulator assembly beyond repair.

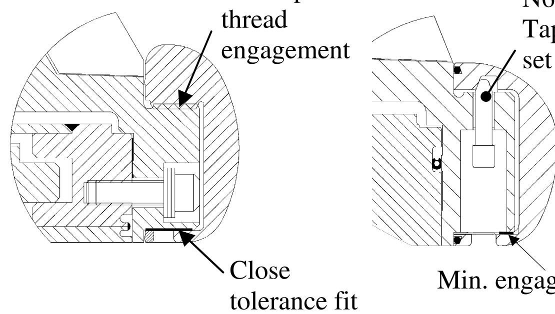

Figure 3. Comparison of legacy cathode cap and new "threadless" cathode cap designs.

The second mechanical problem, which impacts pulse power functionality as well, involves the release of small pieces of silver metal into the cathode and anode triple point regions. During installation, friction between the threads removes small shavings of silver; these metal shavings are subsequently released into the triple point regions reducing voltage holding of the cell. An alternative method using a permanently-applied commercial dry lubricate, "Dicronite", was tested. While this worked successfully in some test cells, the threads eventually galled again and this option was removed from further consideration. It was concluded that the successful implementation of a threaded cathode cap was process intensive and very sensitive to minor imperfections of thread features, such as surface finish, thread engagement tolerances, and small particles.

These problems were solved with the design of a threadless-mounted cathode cap. As shown in Figure 3, the minimal surface engagement feature eliminates the potential for galling, while still maintaining close location tolerances. This mounting method does not use any dry lubricants by the use of six tapered-end set screws made of Nitronic 60 grade stainless steel. Nitronic 60 has anti-galling properties when mated with stainless steel and is suitable for vacuum applications. To maintain uniform current contact, two commercial current conductor springs are installed at the outer and inner grooves of the cathode cap, replacing the legacy "knife-edge" design.

C. Cell Extension Hardware

One cell performance upgrade requires extending the cell by 1-inch. This was accomplished by incorporating two spacer rings: one that extends the dielectric oil volume and one that extends the vacuum beam line volume. The oil volume extension spacer ring (see Figure 1) is an aluminum spacer ring fabricated from a ring forging. The vacuum spacer ring, however, has the added critical requirement of isolating the high vacuum beam tube from the oil volume surrounding it.

The legacy cell design used a narrow tin seal at this sealing interface. However, due to the cold-flow property of tin, the preload on the fastening screws lost their set preload by as much as fifty percent in cells that were in service for less than a year. The concern that the tin would continue to cold-flow during the lifetime of the cell led to investigating other sealing methods for use in the vacuum spacer ring. The new seal would have to reuse the existing sealing surfaces on the solenoid beam tube and insulator cathode flanges, must maintain current contact in the beamline region, maintain its own preload requirements, and must be commercially available. The seal selected was the commercial Helicoflex "Delta" seal. Figure 4 shows a cross section of the vacuum spacer installed in the cell. This seal is used widely in the nuclear power industry and is designed to seal in the ultra-high vacuum regime. Its outer jacket (aluminum) includes two "deltas" that create localized sealing lines. The inner lining creates a support for the outer jacket and is preloaded by an internal helical spring. Compression is controlled by the groove depths of the stainless steel spacer ring. This seal was installed in three prototype test cells. Residual gas analyzer scans performed on two of these cells demonstrated that these seals effectively isolate the oil and vacuum volumes.

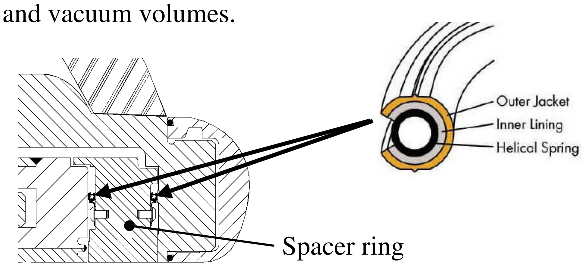

Figure 4. Vacuum spacer and metal seal design

D. Inter-core Insulating Configuration

As shown in Figure 1, electrical insulation is required between the four Metglas induction cores, at the grounded endplate, and at the high voltage drive plate. Each of these interfaces uses a single 0.063-inch thick polyethylene sheet with eight strips of polyethylene slats ultrasonically bonded to the face of the sheet. The ultrasonic bonding is performed at two locations towards the inner radius of the polyethylene sheet. Figure 5 shows a polyethylene sheet/slat assembly prior to installing in a cell. This arrangement creates a gap between the Metglas core and the polyethylene sheet to promote insulating oil flow and prevent air trapping.

Figure 5. Polyethylene/slats ultrasonically bonded assembly

E. High Voltage Drive Plate

Another performance upgrade required modifying the high voltage drive plate to eliminate high electric field potentials and to accommodate the 1-inch cell extension. The high voltage drive plate is comprised of 0.063-inch thick stainless steel welded to a hoop. The resulting modifications include a thinner "ear" connector design to eliminate the large electric field potentials and the addition of pockets to accommodate the longer insulating puck between the high voltage plate and the cell endplate. These pockets are precision stamped using standard sheet metal tooling. Prototypes fabricated and tested demonstrate that precision stamping these pockets is attainable without warping or otherwise adversely affecting the overall shape.

III. RELIABILITY AND MAINTENANCE

A. Beam Tube Oil-Water Interface

A potential problem exists at the oil-water interface of the solenoid beam tube. In up to twelve cases, deionized cooling water was found in the cell's oil volume. As a result, these cells were not pulsed during CD-4d commissioning in December 2002. It is believed that water was introduced into these cells as a result of inadvertent overpressure while the cells were undergoing oil fill in the DARHT-2 hall, relieving the clamping force on the O-ring seals at the oil and water interface. The design of the oil-water interface is shown in Figure 6.

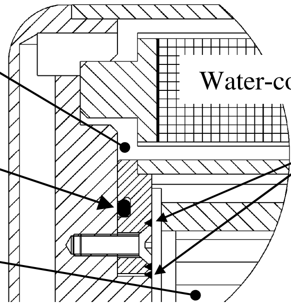

Figure 6. O-ring seal leak area at oil-water interface of solenoid beam tube assembly

Correcting the oil-water interface such that this breach does not reoccur had many restrictions that could lead to permanently damaging the solenoid winding. An option to cool the solenoid with dielectric oil was considered but later dismissed due to the limited energized time, 3-minutes, allowed by a cooling medium with less specific heat capacity. A robust and conservative solution that keeps water as the cooling medium was developed and prototyped. This approach uses a hermetic seal created by welding the cooling jacket flange and the flathead setscrews to the beam tube flange as shown in Figure 6. A helium leak check performed on a full scale prototype demonstrated the effectiveness of this solution, with a leak rate measured at 2.8 x 10^{-10} Torr-l/s. This solution effectively makes the solenoid assembly permanent, and perhaps unserviceable. This is an acceptable risk, given that this solution does not impose restrictions on the operational requirements of the DARHT-II accelerator.

B. Oil Cavity Ventilation Improvements

Improper ventilation of the cell oil cavity has lead to an overpressure that resulted in damage to four cells during oil filling operations. This damage introduced significant quantities of liquid oil into the vacuum volume, requiring a major disassembly and cleanup operation. To prevent this from reoccurring, the cell oil lines and reservoir were redesigned such that all choke points in the legacy configuration were eliminated. Additionally, inline valves and damage-prone quick disconnect fittings were eliminated to prevent accidental sealing of the oil cavity.

C. Detachable Bellows Assembly

During its lifetime, a cell may be disassembled to repair an induction core, replace an anode-cathode insulator, or replace a beam tube solenoid assembly. Currently, access to these components requires cutting off a bellows that is welded to the beam tube assembly. The limited welding material left allows the bellows to be re-welded once. The refurbished cell design incorporates a flanged bellows design that allows the existing bellows to be reattached with fasteners. A Viton O-ring provides the vacuum seal required for high vacuum operation.

IV. MECHANICAL PROCESSES

Implementing these changes on all DARHT-II cells will use production processes that are modeled after Lean Manufacturing principles found in industry today [2]. This topic, as it applies to refurbishing the DARHT-II cells, is discussed by Barraza [3]. As a result, new tooling and assembly techniques have been developed, fabricated, and installed. Examples of new tooling developed include core alignment jigs, a Metglas core cleaning stand, an upright cell transport frame, and various portable templates to perform precision machining operations. The cell refurbishment facility at Los Alamos has been configured to accommodate this new tooling, with workflow divided into seven independent workstations.

Quality assurance (QA) and quality control are an integral part of the cell refurbishment process. A cell refurbishment manual was developed to promote quality control at the floor level operations. This manual contains floor level tools such as work checklists, process travelers, QA and technical releases, alignment data, process data records, subcomponent data records, inspection records, and acceptance criteria requirements. This supports a high level of consistency throughout the entire DARHT-II cell refurbishment project.

V. SUMMARY

A baseline cell mechanical design that incorporates redesigns in both the oil and vacuum regions has been completed. These redesigns resulted in new and modified components. In addition, improvements related to cell reliability and maintenance were adopted. Among all changes to the cell design, the most challenging mechanical upgrades of the baseline cell design include the flatface-2 insulator geometry, the threadless cathode cap mounting, the incorporation of a commercial, all-metal vacuum seal, and remediation of the beam tube solenoid oil-water interface leak. Other reliability measures were also adopted that prevent accidental damage to the cell during maintenance and facilitates any future disassembly and assembly operations.

A new production process that includes new tooling and a new production facility layout was developed to promote repeatable and reliable cell assemblies. A robust quality assurance program centered on floor-level activities promotes assembly consistency throughout the cell refurbishment project.

VI. REFERENCES

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